Convergence

Advancing Robotic Wire Arc Additive Manufacturing to the Architectural Scale in an Urban Context

Jenny E. Sabin, Michael Paraszczak, Dillon Pranger, John Hilla

Convergence celebrates the thriving, vibrant, and rich heritage of excellence of the University of Nebraska Medical Center through materialized concepts that embed change, transformation, and contemplation. The project incorporates the most advanced methods and innovations in digital and robotic fabrication with the integration of timeless and contextually sensitive materials that interact with the sun and human perception. The project features stainless steel wire arc additive manufacturing through robotic 3D printing, nonstandard CNC machined polycarbonate panels laminated with responsive wavelength-dependent dichroic film, and stainless-steel stiffener rings. Sited in the new Northwall Plaza, *Convergence* serves as the outdoor threshold to the buildings and the campus welcome center facilitating an ideal setting for conversations, fellowship, and engagement by students and faculty.

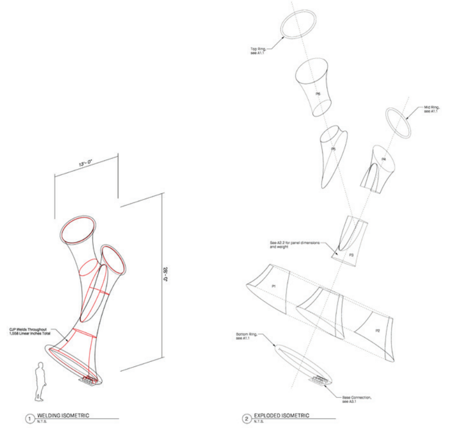
The largest 3D printed stainless steel sculpture in the world, *Convergence* builds on the expanding field of architectural additive manufacturing through a unique collaboration with Lincoln Electric by pushing the boundaries of architectural scale seen in the wire arc additive manufacturing (WAAM) process. The WAAM fabrication process was previously brought into the architectural space by ARUP in their research into optimizing metal structural building elements (Galjaard et al. 2015). The design opportunities of this emerging method were showcased in the "MX3D" Bridge project designed and developed by the Joris Laarman Lab and MX3D (Laarman 2018). Designers are just starting to explore this new opportunity for melding the versatility and efficiency of 3D printing with the strength of metallic materials.

Roland Snooks expanded on this new method in "Remnants of a Future Architecture" exhibited at Melbourne Design Week 2022 (Snooks 2022). At 28 feet in height and 12 feet in diameter, *Convergence* acts as a beacon in the UnMC plaza and pushes WAAM to the architectural scale in an urban university context. Through the unique WAAM process, the structure—at 4,000 lbs of robotically 3D

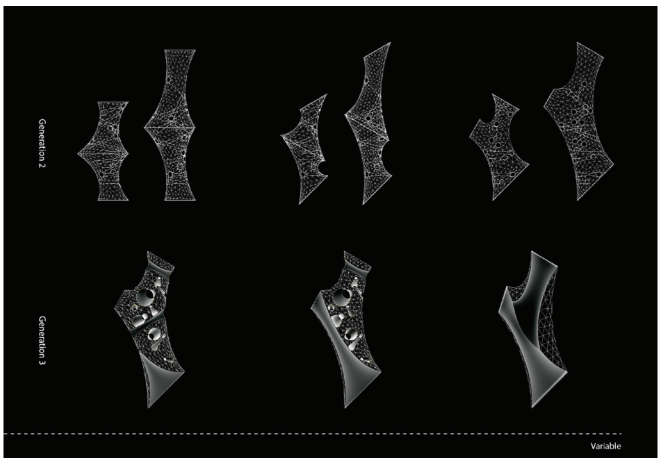
PRODUCTION NOTES

Architect:	Jenny Sabin Studio
Client:	University of Nebraska Medical Center and the Nebraska Arts Council, 1% for Art Program
Status:	Built
Site Area:	28' height x 12' diameter
Location:	Omaha, Nebraska
Date:	2021

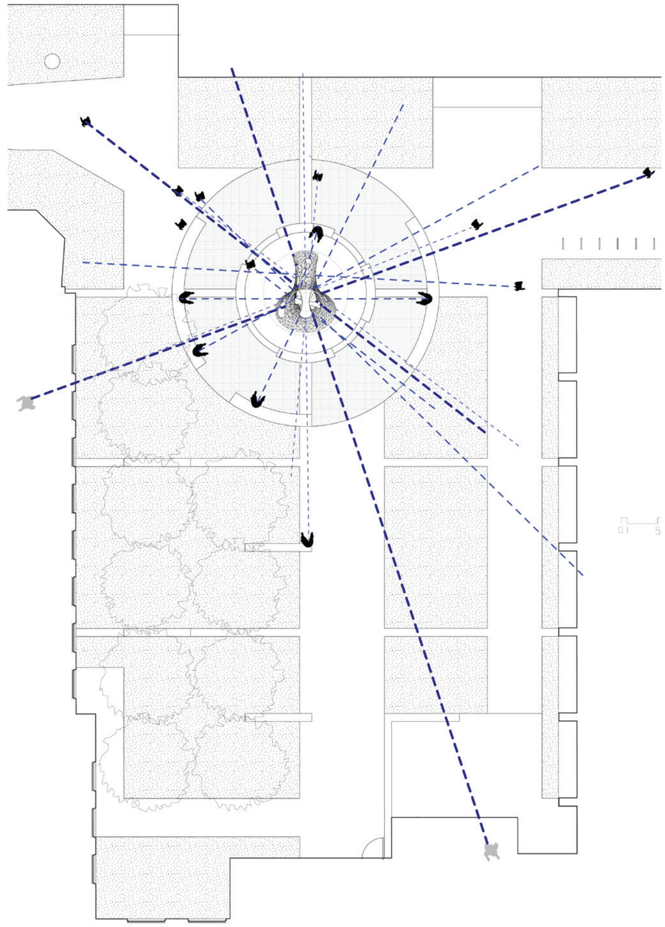
1 Opening of *Convergence* at UNMC Northwall Plaza (Jenny Sabin Studio, 2021)



2 Fabrication planning diagram: the central spine was split into nine total parts to reduce overhang, thermal distortion, and print error



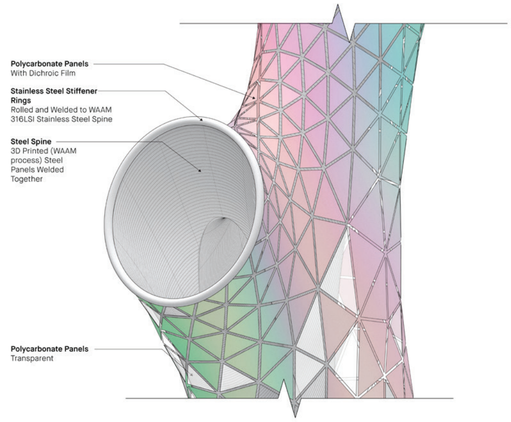
3 To amplify the spatial presence of the project through equal and opposite forces, the interactive form-finding process included anchoring and balancing the structure on a single point that meets the foundation in the plaza



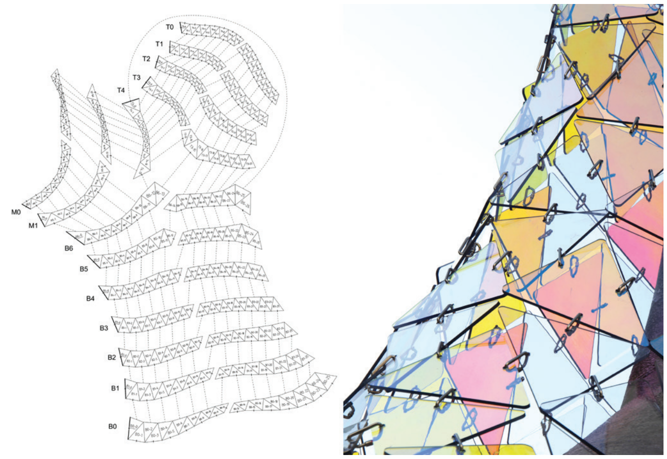
4 Generative design process, including site and view analysis of the plaza; voids within the project were calibrated and optimized relative to views from adjacent public balconies and from the plaza grounds looking through the structure

printed stainless steel material organized in nine unique printed panels—uses less steel material than traditional fabrication methods, thus reducing waste and saving time and labor.

The design process for *Convergence* commenced with a comprehensive site analysis of the local plaza and its connections to other permanent works of public art on campus. Our form-finding process was developed with custom scripts in Kangaroo, an interactive real-time physics engine for simulating dynamic forces. Voids within the project were calibrated, iterated, and optimized relative to views from adjacent public balconies and from the plaza grounds looking up and through the structure. Working closely with Lincoln Electric, fabrication constraints, such as scale of parts and maximum draft angle or overhang within the panels, were integrated and optimized. For example, during two test prints at Lincoln Electric, 3D scans of the finished parts revealed substantial thermal distortion at some locations of the part whereas others nearly matched the CAD model. After further tests, it was determined that a print deviation of less than 0.125 inch was acceptable from an engineering perspective for final fabrication and welding fit-up of all parts into the singular spine structure. Further, due to the steep draft angles, extra material—such as flat panels—was added to the CAD model to stabilize the part during the printing process. These areas were then removed during the finishing phase. The fabrication strategy used a single welding process, stacked vertically in an additive method. Specifically, BLUE MAX® MIG 316LSI stainless steel was used to additively manufacture each of the nine 0.25” thick parts via Wire Directed Energy Deposition (Wire DED) on a

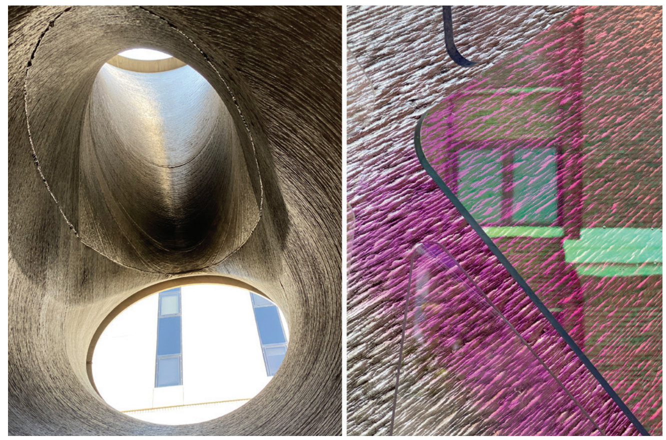


5 Material and structural diagram highlighting the polycarbonate dichroic mesh, WAAM steel spine, and stainless steel ring stiffeners



7 To fabricate the panels, 0.75" polycarbonate flat sheets were laminated with wavelength dependent dichroic film and cut via CNC process

6 Section C of the project being printed in a cell at Lincoln Electric; BLUE MAX® MIG 316LSI was used to additively manufacture each of the nine 0.25" thick parts via Wire Directed Energy Deposition (Wire DED) on a 0.5" thick ASTM A36 base plate; the method of DED was GMAW-Pulse



8 Material details of *Convergence*: interior of the 3D printed stainless steel spine (left); detail of the exterior of the steel structure featuring a texture of continuous layers of WAAM steel and dichroic mesh panels (right)

0.5" thick ASTM A36 base plate. This base plate was later removed during the final fabrication and weld fit-up of the spine structure. The material was selected after two cylindrical tests were produced by Lincoln Electric. Initially, attempts were made to remove the presence of visible arc start locations through grinding and wire brushing, but it was determined that this would create noticeable grind patches; due to labor, cost, and time, the ribbed texture with periodic drips or bumps where the welding arc starts was preferred as it provides a beautiful texture and narrative of the project's robotic wire arc production. In collaboration with Lincoln Electric and during the tool path planning process, it was determined that due to the size of the prints—the largest measuring at 7 feet tall—the start and stop locations of the fabrication process had to be situated on the side of the part closest to the robot. Once the printing process was completed at Lincoln Electric, all parts were shipped to our fabricator in Omaha for final fabrication, welding, and finishing.

During the robotic fabrication testing phase and design iterations of the spine, form-finding experiments were conducted to generate the exterior tessellated mesh composed of clear and dichroic triangular components. The surface was treated as a fabric membrane and simulated in Kangaroo with anchors situated at the three ring locations of the central spine. These digital outputs were then tested at model scale through physical prototypes. Finally, in collaboration with our engineers, a strategy was developed and scripted to place and coordinate holes in each panel to stitch and connect the mesh assembly together. Strips of the mesh were assembled with stainless steel carabiners and flat packed for shipment to Omaha, Nebraska.

9 Attempts were made to remove the presence of visible arc start locations through grinding, but it was determined that this would create noticeable grind patches; due to labor, cost, and time, the ribbed texture with periodic bumps provided a beautiful texture and narrative of its robotic wire arc production

10 *Convergence* at night casting dynamic color and light; gradient studies were scripted to test variations in density of the dichroic and clear polycarbonate panels to optimize and highlight reflected and refracted light as washes of color and shadow during the day and night

As a set of integrated material relationships, the design for *Convergence* incorporates part-to-whole 3D printed and machined component strategies to realize a project that celebrates lightness, dynamic structure, and equilibrium through equal and opposite forces. Taking inspiration from the University of Nebraska Medical Center's pivotal role in global health through their response and leadership in both the Ebola epidemic and now the Coronavirus pandemic, *Convergence* celebrates people coming together from around the world. Through part-to-whole, individual, and collective, the project reflects and celebrates the faculty, doctors, students, researchers, administrators, and community champions who have left their mark and defined UNMC's past, present, and future.

ACKNOWLEDGMENTS

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REFERENCES

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Laarman, Joris. 2018. "MX3D Bridge." Amsterdam, Netherlands: Dutch Design Week.

Snooks, Roland. 2022. "Remnants of Future Architecture." Melbourne, Australia: Melbourne Design Week.

IMAGE CREDITS

11 After the spine was assembled and welded together, the 28-foot structure was passivated and wire-brushed to remove residue from the printing process, protect the stainless steel from the outdoor elements, and enhance the luster of the steel material. Due to constraints of the site, a crane rigged and hoisted the structure over a sky bridge before setting and mounting it to its foundation. After the spine was bolted in place, the strips of the polycarbonate surface were installed concentrically and connected with stainless steel carabiners. Finally, turnbuckles were added at each stainless-steel ring termination allowing for tension adjustments to the surface.

Jenny E. Sabin is the Arthur L. and Isabel B. Wiesenberger Professor in Architecture and Associate Dean for Design at Cornell College of Architecture, Art, and Planning where she established a new advanced research degree in Matter Design Computation. She is principal of Jenny Sabin Studio, an experimental architectural design studio based in Ithaca and Director of the Sabin Lab at Cornell AAP. In 2017, Sabin won MoMA & MoMA PS1's Young Architects Program with her submission *Lumen*.

Michael Paraszczak holds a MArch from Cornell University and is a Junior Designer with Jenny Sabin Studio. Paraszczak holds a BS in Architecture from SUNY University at Buffalo and has additional experience working in the design office of REX and as technician at the University at Buffalo Fabrication Workshop.

Dillon Pranger is a licensed architect in the State of Illinois and is Associate Architect with Jenny Sabin Studio. He holds a BS in Architecture from the University of Cincinnati, and a MArch from Cornell University. Pranger has taught extensively at institutions such as Cornell AAP, Harvard GSD, and Syracuse University SOA, with additional experience working in the design offices of KPF and Eisenman Architects.

John Hilla is a Senior Designer with Jenny Sabin Studio, a Research Associate with JSLab, and a recipient of the American Institute of Architects Henry Adams Medal. Hilla holds a MArch from the University of Pennsylvania, as well as a BS in Mechanical Engineering and a MS in Engineering Management from Syracuse University.